EAGE

SECOND EAGE/SBGF CONFERENCE ON

DEEPWATER

BRAZIL EQUATORIAL MARGIN

26-28 MAY 2026

RIO DE JANEIRO | BRAZIL

Reducing the Environmental Impact of Seismic Surveys: A Review of Impulsive Source Technologies and Monitoring Solutions

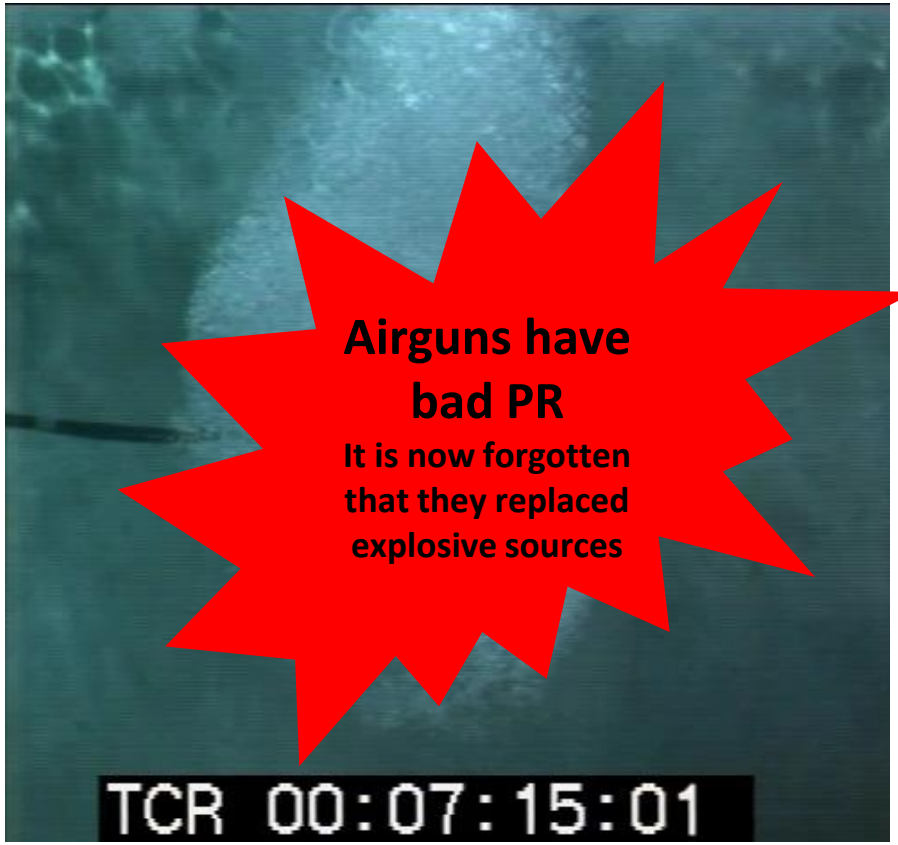
Julien Large, Guillaume Bessiere, Thibaut Cappe de Baillon, Claire Dorlet, Shuki Ronen, Jeremy Aznar

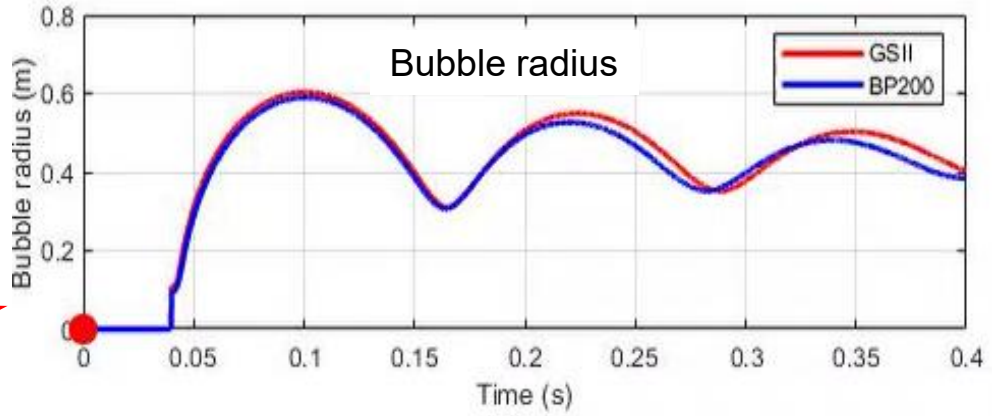
SERCEL

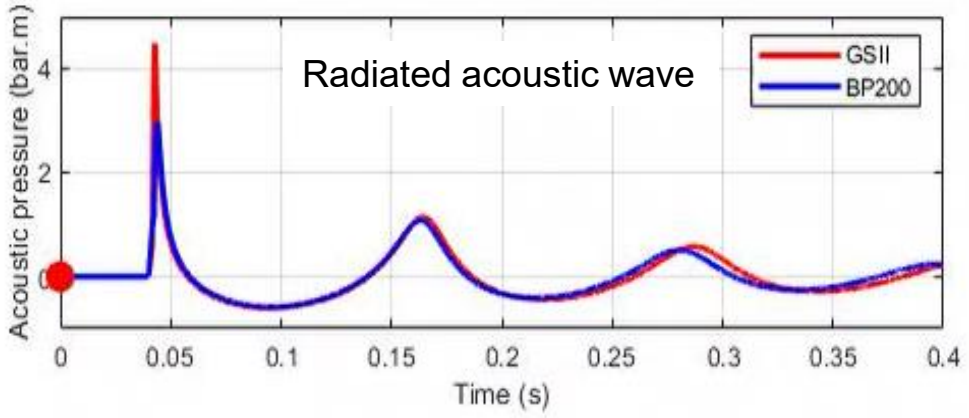
Stanford University

Impulsive source (Airgun)

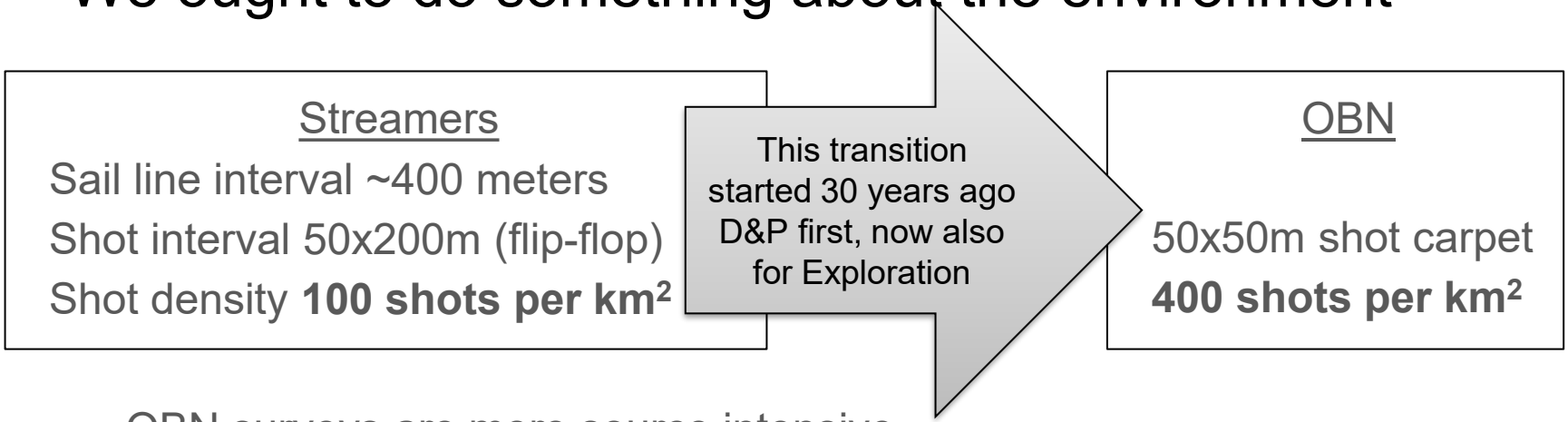
We ought to do something about the source





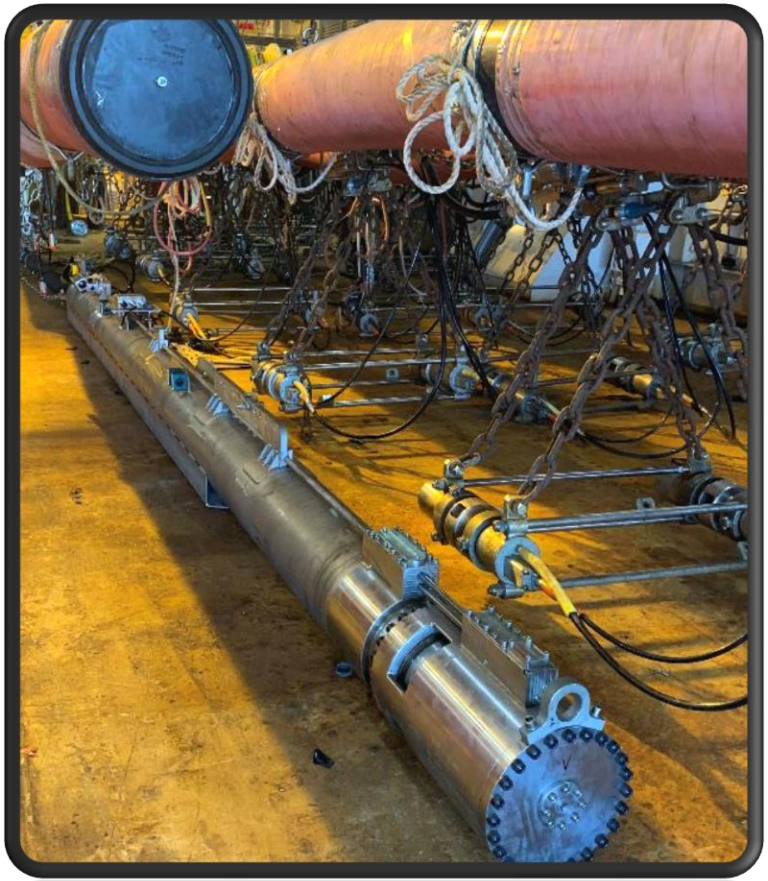


We ought to do something about the environment



- OBN surveys are more source intensive
- It is faster to shoot then to move nodes
- One ROV vessel moving nodes can be balanced by two or three source vessels
- Deblending in data processing is working (surprisingly?) well
- We need **seismic sources with lower environmental impacts**
- We need data to support effective **monitoring and mitigation**

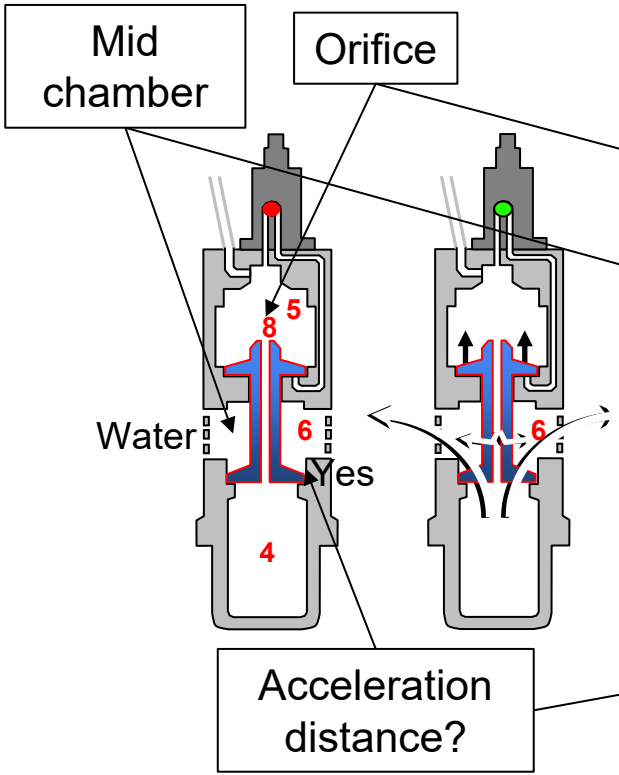
Tuned Pulse Source compared to Airguns







Design features: TPS ≠ Airguns



Feature	TPS	Airgun	Purpose
Mid-chamber (6)	Air filled	Water flooded	**Avoid cavitation**
Acceleration distance	Zero	A few cm	**Reduce slope**
Orifice (8)	Direct	In the shuttle	**Prevent auto-fires**

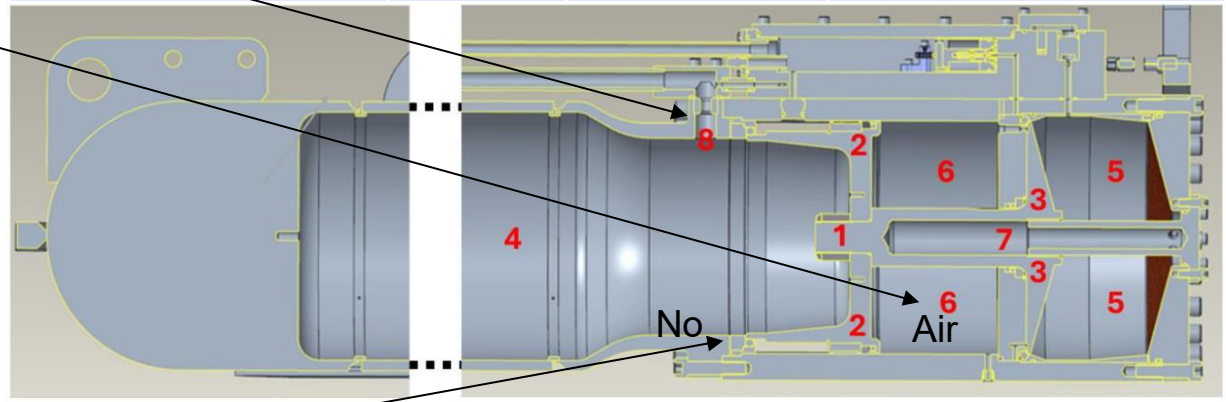
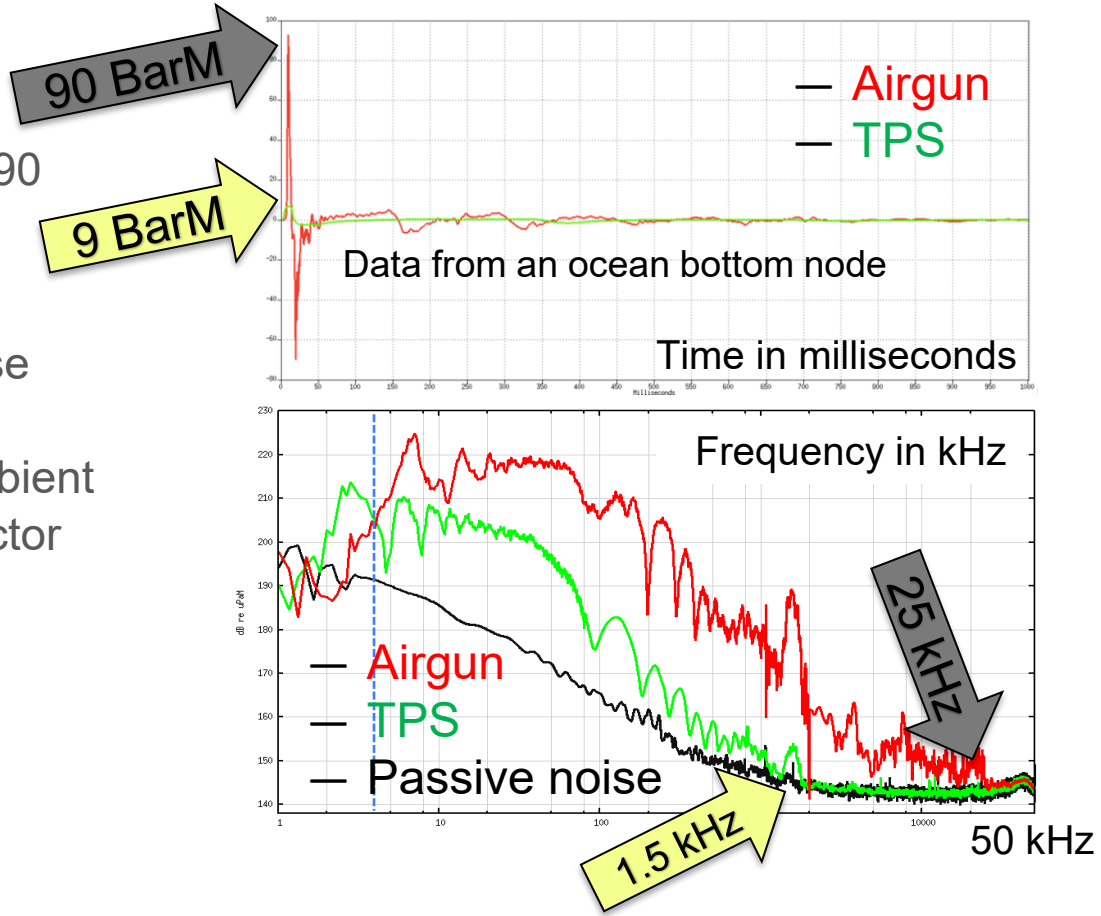


Figure 9. Schematic cross-section of the TPS. The shuttle assembly (1) consists of a shaft and two pistons: a firing piston (2) and an operating piston (3). This source contains four air-filled chambers: the large firing chamber (4), the operating chamber (5), the mid chamber (6), and the shaft chamber (7), which collectively control piston motion and prevent ballistic behavior. The use of air in all chambers avoids cavitation—a common issue in water-filled air guns. Air is supplied and drained via an orifice (8) located outside the shaft, preventing unintentional auto-fires and enhancing crew safety.

TPS: 1/10th the SPL and ~30dB less high frequency

- Time domain
  - ✓ Bar-meter: <9 compared to >90
  - ✓ More than 20 dB
- Frequency domain
  - ✓ TPS spectrum ~ ambient noise spectrum at 1.25 Hz
  - ✓ Airgun spectrum joins the ambient noise spectrum at 25 kHz (factor 20 higher)

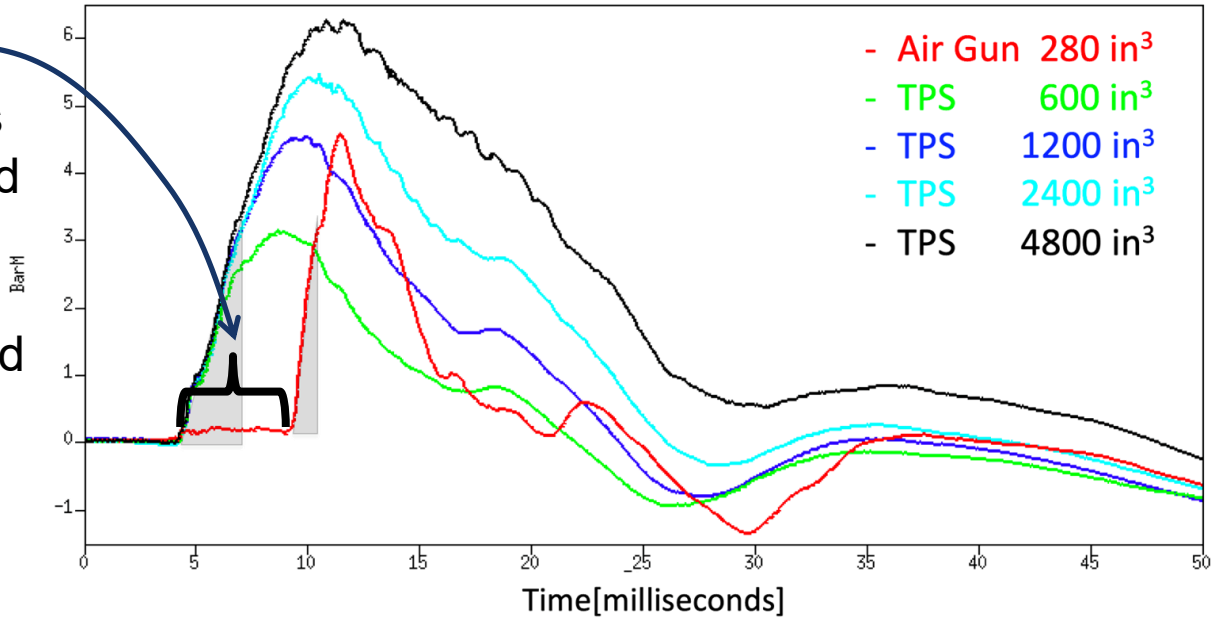
Data from a special node
Δt=10 microsecond
Nyquist frequency = 50 kHz



Slope and shoulder

The shoulder

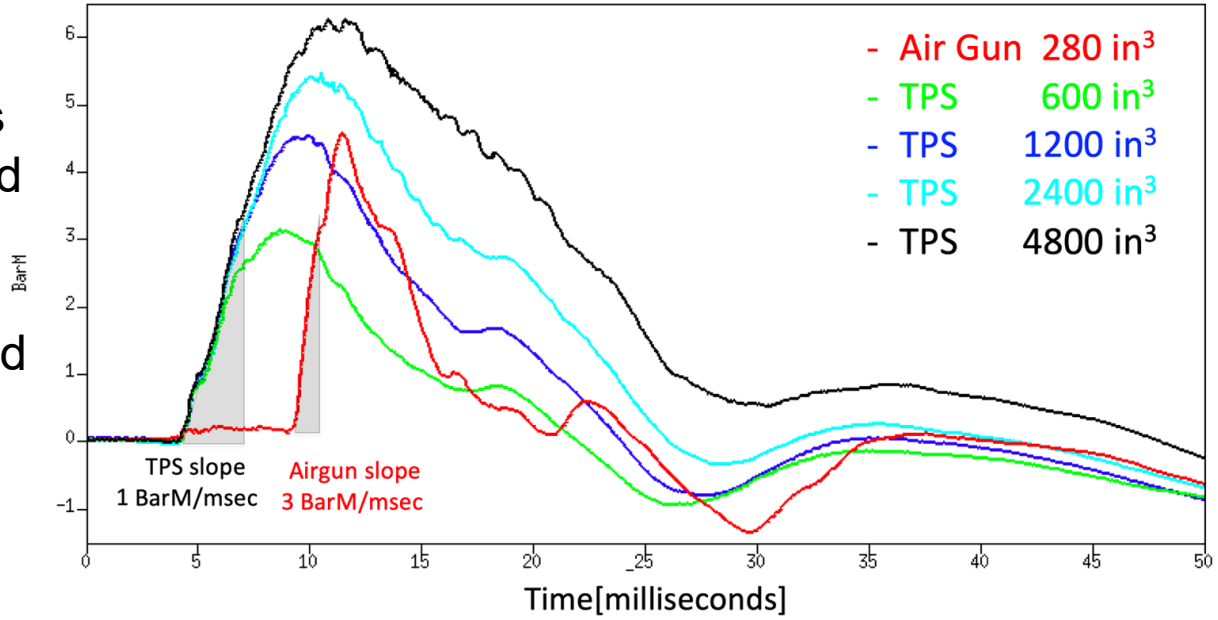
- The shuttle accelerates
- Air is not yet discharged through the ports
- The water in the mid chamber are discharged
- Cavitation **(bad!)**
- Only Airguns
- TPS has no shoulder



Slope and shoulder

The shoulder

- The shuttle accelerates
- Air is not yet discharged through the ports
- The water in the mid chamber are discharged
- Cavitation **(bad!)**!
- Only Airguns
- TPS has no shoulder

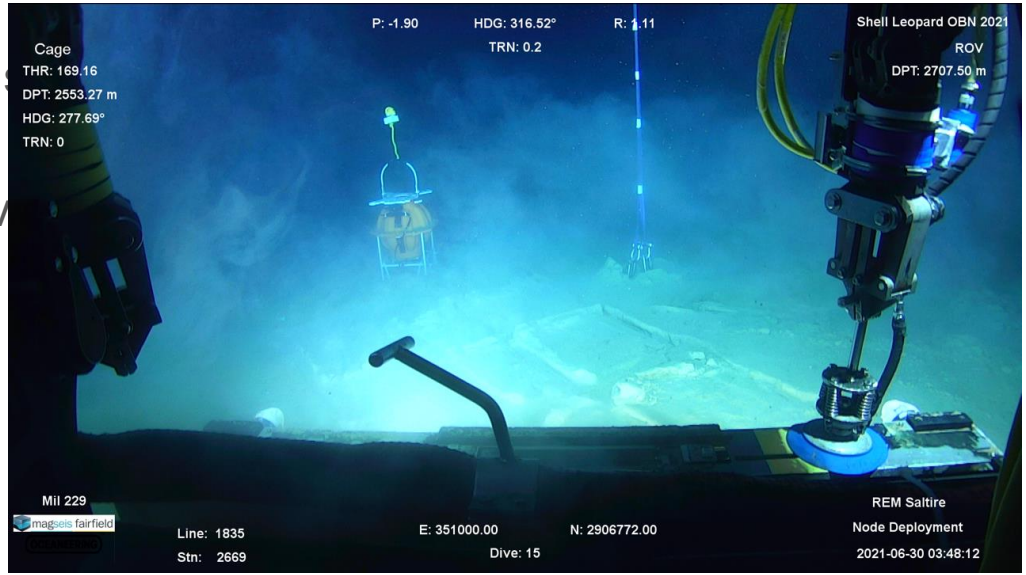


- **The Slope**

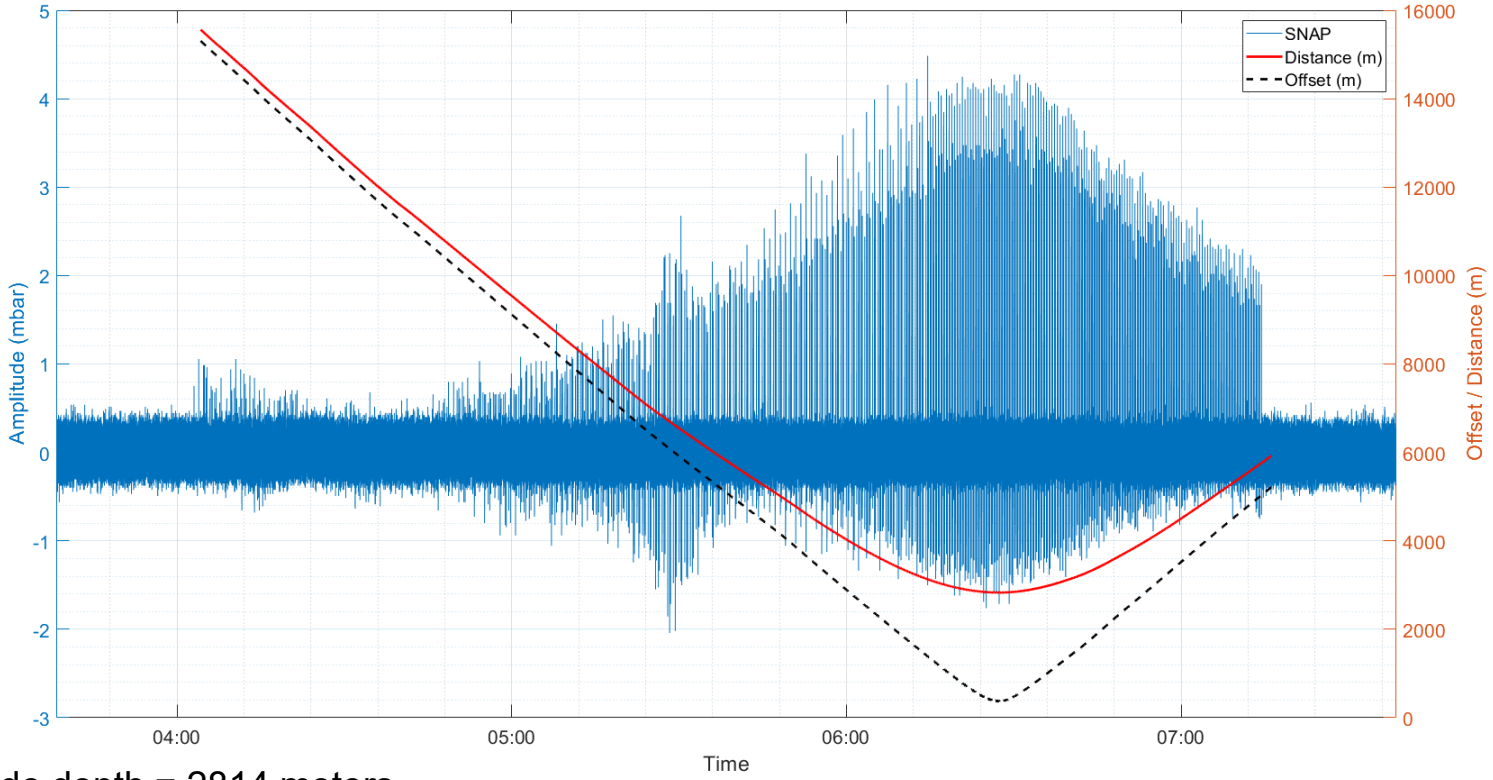
- Airguns' slope is x3 higher because the ports open faster
- Pressure is proportional to particle velocity
- Slope is proportional to particle acceleration
- Acceleration is proportional to force → **we want to reduce the slope**

Environmental impact data—example

- Ocean Bottom Node: Sercel operated Loggerhead SNAP
- Deployment and retrieval: ROV operated contracted by TGS
- Gulf of Mexico, 2021
- Depth 2707, 2815 meter (2 OBNs
- Continuous recording
- 10 microseconds sampling interv
- 100 kHz sampling frequency
- 50 kHz Nyquist frequency
- Apples-to-apples sources
- Co-located Airgun, TPS, Gemini
- Customer: Shell

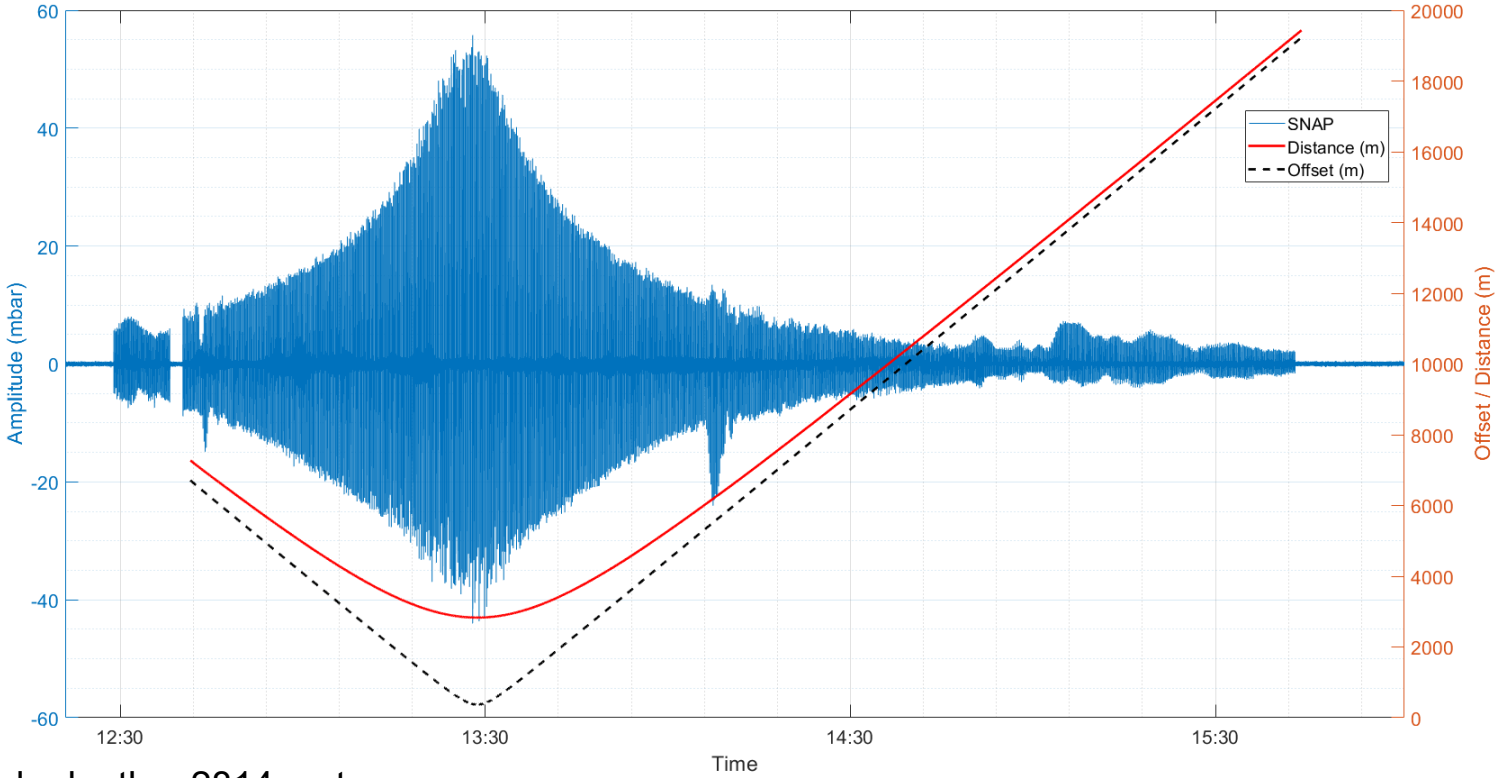


Continuous data—TPS max 4 mbar, min -1.5 mbar



Node depth = 2814 meters

Continuous data—Airguns max 50 mbar, min -40 mbar



Node depth = 2814 meters

Tuned Pulse Sound Source Characterization in Gulf of Mexico

JASCO Applied Sciences (USA) Inc.

19 December 2023

Submitted to:
Marc Rocke
TGS
Work Order signed 28 August 2023

Authors:
S. Bruce Martin
Carmen B. Lawrence
Julien J.-Y. Delarue
Colleen C. Wilson

P001753-001
Document 03240
Version 1.0

Jasco is independent of the oil industry
- ✓ Data
- ✓ Not Sercel

JASCO APPLIED SCIENCES



- Jasco is an environmental service provider
- They recorded **data from 2X28 Kcui TPS** and from a 5Kcui array of Airguns
- They analysed the data and issued a (62 page) report
- They compared TPS to Airguns on
    1. Exposure distance
    2. Available listening range

Exposure Distance

This trial allowed for a direct comparison of the received sound levels of a typical airgun array (5000 in^3), with a single or dual tuned pulse source. Assuming the seismic imaging quality of the sources is comparable, the TPS is strongly preferred from a marine mammal sound exposure viewpoint. The sound exposure levels produced by dual TPS were 10–14 dB lower for LF mammals, and 28–29 dB lower for HF and VHF mammals. This equates to at least a 3-fold reduction in exposure distance and 9-fold decrease in exposure area for LF mammals. For the HF and VHF mammals, the distances are reduced by a factor of 25 and the area by a factor of 625.

Exposure distance
Factor 3 to 25 smaller than Airguns!
(Depending on the species)

Executive Summary

JASCO Applied Sciences (JASCO) was contracted by TGS to undertake a sound source characterization (SSC) study of the tuned pulse source (TPS) in the Gulf of Mexico from 31 August to 7 September 2023. The SSC involved collecting and analyzing data and interpreting the results, focusing on understanding

vocalization behavior may have occurred, or the animals avoided the area when sources were active.

This trial allowed for a direct comparison of the received sound levels of a typical airgun array (5000 in^3), with a single or dual tuned pulse source. Assuming the seismic imaging quality of the sources is comparable, the TPS is strongly preferred from a marine mammal sound exposure viewpoint. The sound exposure levels produced by dual TPS were 10–14 dB lower for LF mammals, and 28–29 dB lower for HF and VHF mammals. This equates to at least a 3-fold reduction in exposure distance and 9-fold decrease in exposure area for LF mammals. For the HF and VHF mammals, the distances are reduced by a factor of 25 and the area by a factor of 625.

With respect to distances for behavioral disturbance, the shallow water yielded substantially longer disturbance distances in most cases. The distances at which 50 % of the individuals of sensitive species are likely to be disturbed were 5–20 km, while those distances were 1.1 km or less for the less sensitive species such as dolphins and sperm whales. In all cases the distances for the airguns were at least double those for the dual TPS, and the dual TPS distances were greater than for the single TPS.

The percentage of the normal available listening range (ALR) for marine mammals was computed as an index of communication masking. Since seismic pulses are known to reverberate, the amount of time after a pulse that is masked is of interest. The ALR was reduced for 1–2 seconds after the pulse when the source as up to 10 km away, compared to ~5 seconds for the airgun arrays. Substantial masking was found due to the tow vessel. The vessel sounds would cause substantial masking within 5 km for the 80 Hz downsweep of Rice's whales and within ~2 km for the dolphin whistles. Those distance are longer in shallow water than deep.

Available Listening Range

The percentage of the normal available listening range (ALR) for marine mammals was computed as an index of communication masking. Since seismic pulses are known to reverberate, the amount of time after a pulse that is masked is of interest. The ALR was reduced for 1–2 seconds after the pulse when the source as up to 10 km away, compared to ~5 seconds for the airgun arrays. Substantial masking was

ALR ~ Duty cycle:
Up to factor 5 times better than Airguns

Executive Summary

JASCO Applied Sciences (JASCO) was contracted by TGS to undertake a sound source characterization (SSC) study of the tuned pulse source (TPS) in the Gulf of Mexico from 31 August to 7 September 2023. The SSC involved collecting and analyzing data and interpreting the results, focusing on understanding potential impacts on marine mammals. The scope of the study was to determine the relative sound levels of the TPS within the hearing bands of marine mammals compared to standard airgun surveys. Data were collected using a walk-away pattern that sampled the endfire sound levels from 17500 m north of the recorders to 20000 m south. Broadside lines 5 km long were run with offsets of 170, 670, 1920 and 3920 m. Three sources were measured – a 5000 in³ airgun array, a 28000 in³ TPS and a dual 28000 in³ TPS configuration. Each source fired once every 60 seconds.

The source characterization hydrophones were deployed on long-line moorings to sample at a depth of ~100 m. The water depth at the deployment site was 450 m. The start of the measurement lines to the

vocalization behavior may have occurred, or the animals avoided the area when sources were active.

This trial allowed for a direct comparison of the received sound levels of a typical airgun array (5000 in³), with a single or dual tuned pulse source. Assuming the seismic imaging quality of the sources is comparable, the TPS is strongly preferred from a marine mammal sound exposure viewpoint. The sound exposure levels produced by dual TPS were 10–14 dB lower for LF mammals, and 28–29 dB lower for HF and VHF mammals. This equates to at least a 3-fold reduction in exposure distance and 9-fold decrease in exposure area for LF mammals. For the HF and VHF mammals, the distances are reduced by a factor of 25 and the area by a factor of 625.

With respect to distances for behavioral disturbance, the shallow water yielded substantially longer disturbance distances in most cases. The distances at which 50 % of the individuals of sensitive species are likely to be disturbed were 5–20 km, while those distances were 1.1 km or less for the less sensitive species such as dolphins and sperm whales. In all cases the distances for the airguns were at least double those for the dual TPS, and the dual TPS distances were greater than for the single TPS.

The percentage of the normal available listening range (ALR) for marine mammals was computed as an index of communication masking. Since seismic pulses are known to reverberate, the amount of time after a pulse that is masked is of interest. The ALR was reduced for 1–2 seconds after the pulse when the source as up to 10 km away, compared to ~5 seconds for the airgun arrays. Substantial masking was found due to the tow vessel. The vessel sounds would cause substantial masking within 5 km for the 80 Hz downsweep of Rice's whales and within ~2 km for the dolphin whistles. Those distance are longer in shallow water than deep.

California Ocean Alliance (COA)

COA is independent of the oil industry

Reducing Impacts of Anthropogenic Noise to Cetaceans

in the Gulf of Mexico:

Collaborating with Industry on Noise Reduction Pilot Projects

Recommended Options Paper

Project Team and report Co-Authors:

Brandon Southall (lead investigator; California Ocean Alliance)

Michael Bahtiarian (Acentech, Inc.)

Kevin Boswell (Florida International University)

Michael Jenkerson (MJ.Pegasus, LLC.)

John Joseph (Naval Postgraduate School)

Tetyana Margolina (Naval Postgraduate School)

Megan McKenna (California Ocean Alliance)

Doug Nowacek (Duke University)

Rob Schick (California Ocean Alliance)

California Ocean Alliance (COA)

Exposure radius
↓
Noise footprint

Taking the bathymetry and water velocity profile into account

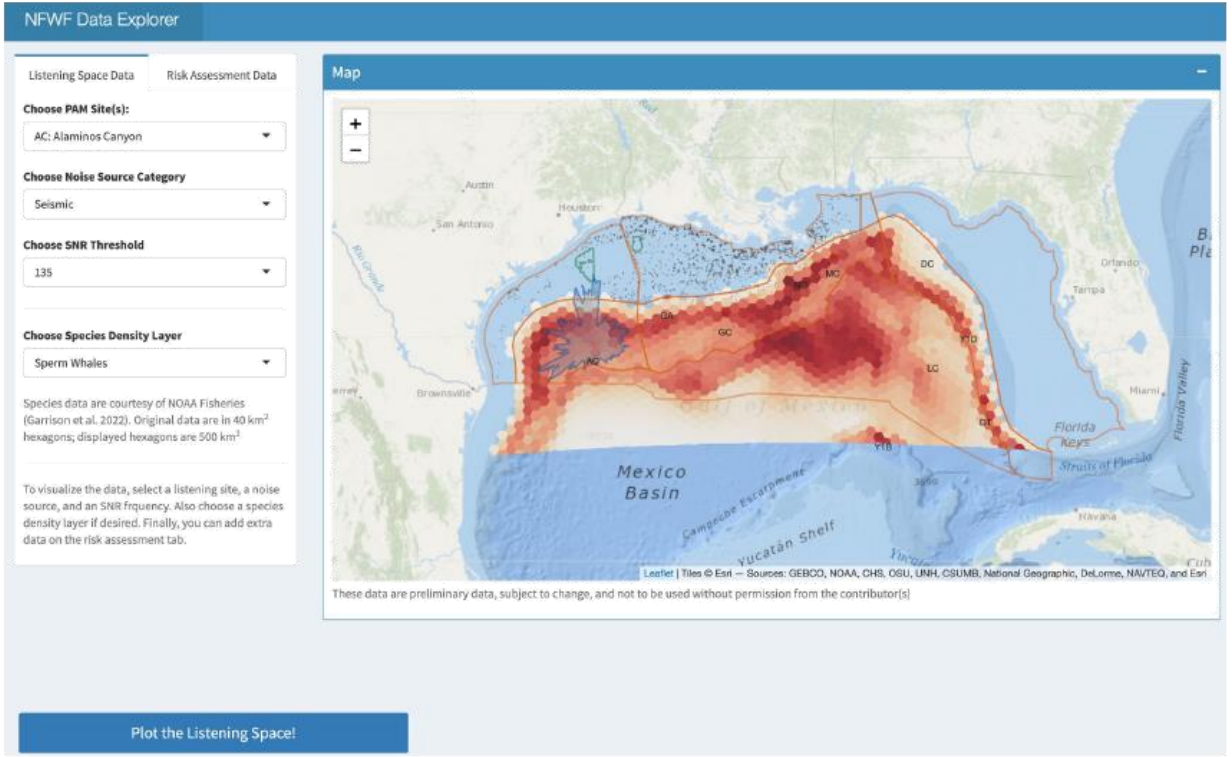
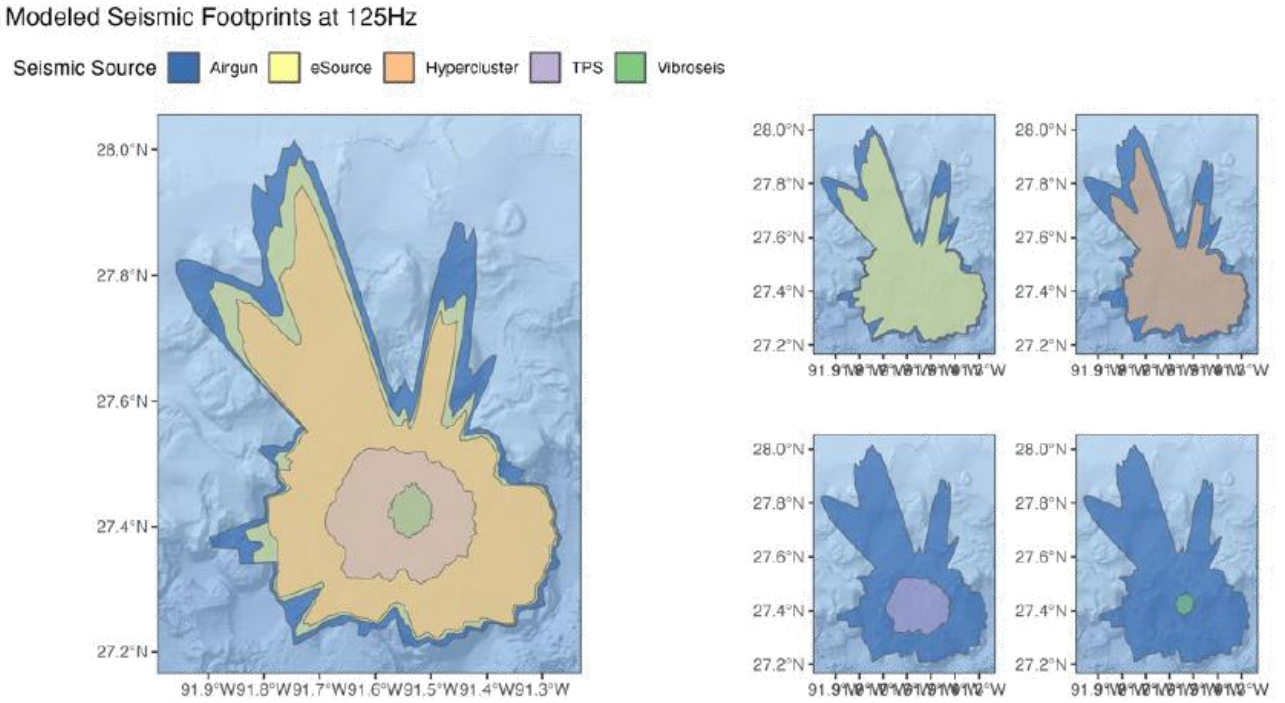


Figure 1. Illustration from data exploration tool highlighting the spatial relationship of the listening space (shown here (blue polygon) for a seismic source at Alaminos Canyon) in relation to sperm whale density (orange hex cells), wind energy lease areas (green polygons), active rigs (black dots), and the BOEM-identified GoMex marine mammal spatial zones used in the relativistic risk assessment (orange polygons).

California Ocean Alliance (COA)

« Noise footprint »



Airgun

eSource

TPS

Hypercluster

Vibroseis

Figure 3. Modeled noise footprints at 125 Hz for five seismic survey sources for low-frequency cetaceans. All sources are shown relative to one another in the stacked plot (left) and each alternative technology shown relative to conventional seismic airgun for reference (right).

California Ocean Alliance (COA)

Exclusion radius → « Noise footprint »

TPS is more like Marine Vibe than like Airguns

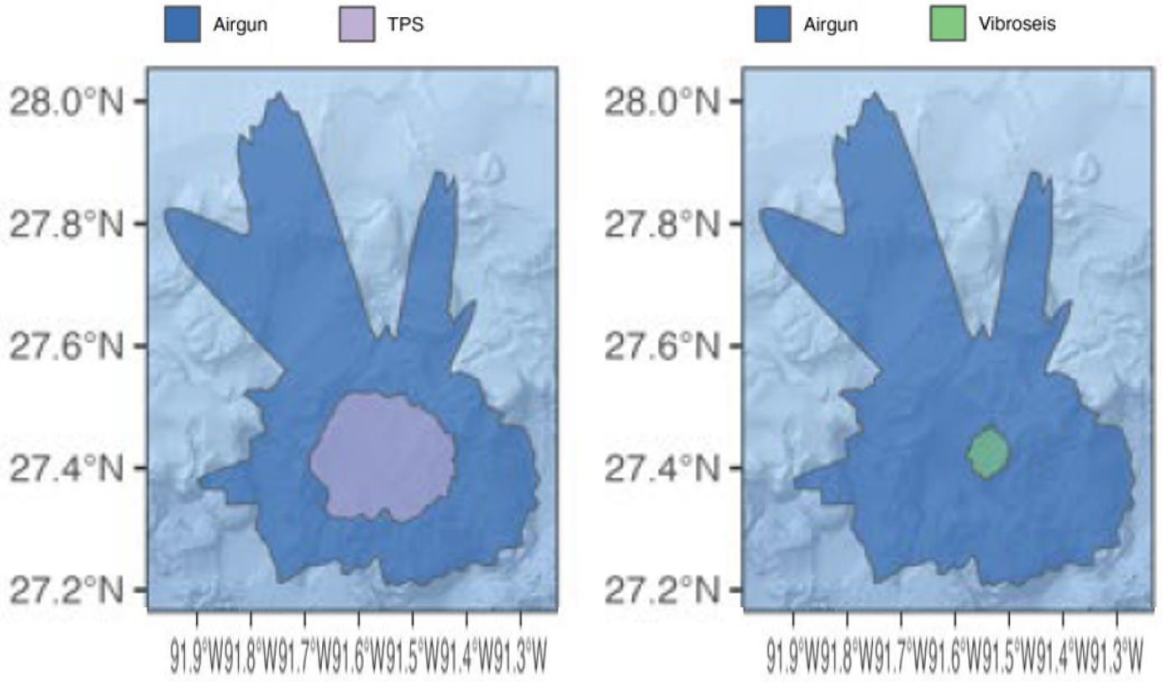
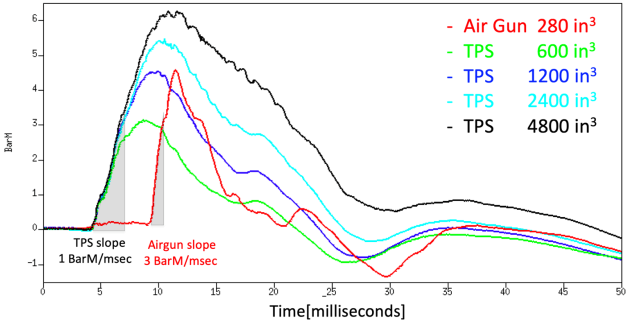
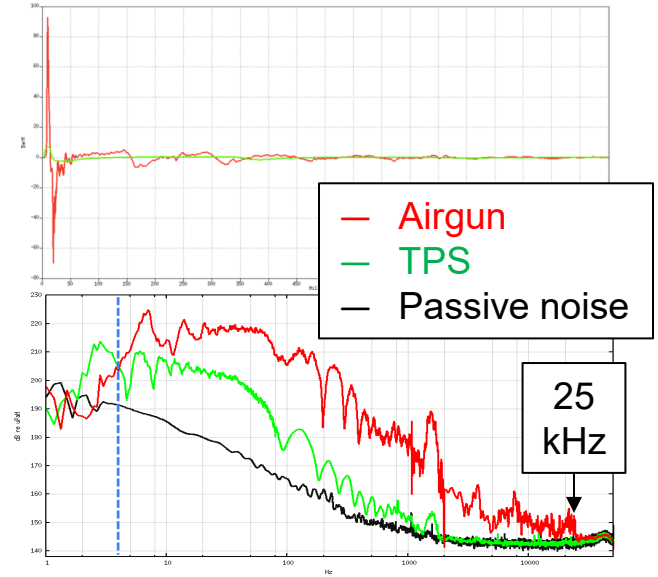


Figure 3. Modeled noise footprints at 125 Hz for five seismic survey sources for low-frequency cetaceans. All sources are shown relative to one another in the stacked plot (left) and each alternative technology shown relative to conventional seismic airgun for reference (right).

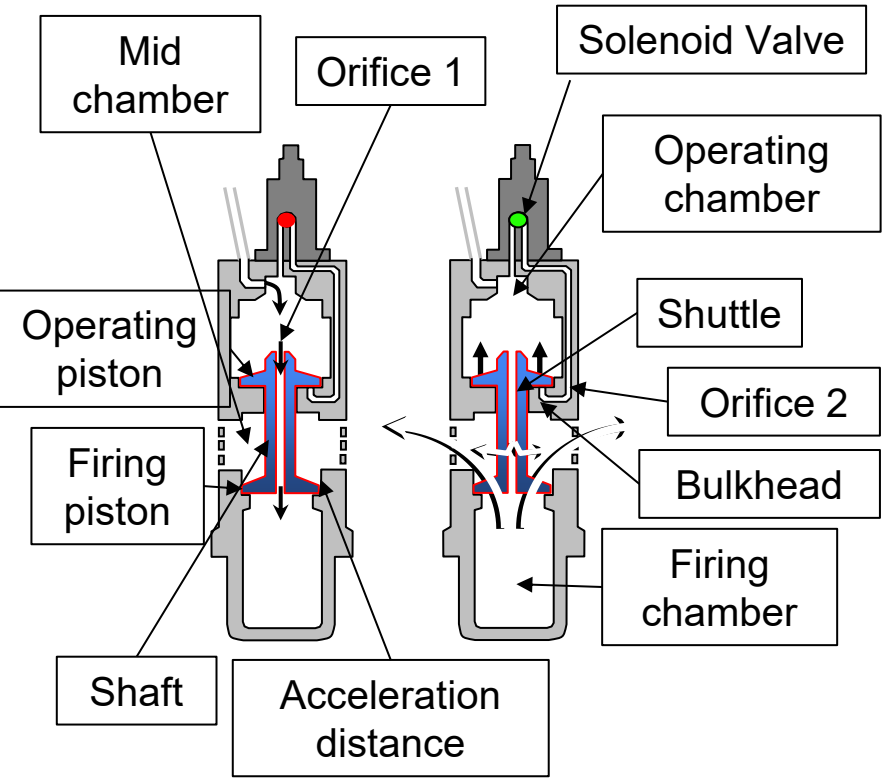
Summary

	Airguns	Gemini/Harmony	TPS
Head Design	Old	Old	New
Mid-chamber	Water-flooded	Water-flooded	Air-filled
Cavitation	25 kHz	Not published	1.5 kHz
Pressure	2000 PSI	2000 PSI	1000 PSI
Max SPL	5 BarM each	Not published	9 BarM
Deployment	Arrays of up to 33 guns	Cluster of 2 to 6 heads	Single point source
Max slope	3 BarM/msec each	Not published	1 BarM/msec
Auto-fires	Yes. When drained	Not published	No





Airguns' design

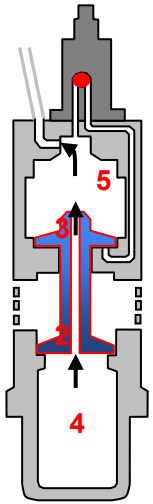


1. Ready to fire
- Same pressure in both chambers
- The area of the operating piston is larger than the area of the firing piston
- The down force on the operating piston is larger than the up force on the firing chamber

2. Triggering
- A capacitor is discharges through the coil of the solenoid valve and high pressure air flows through orifice 2 into a circular groove in the bulkhead (under the operating piston)
- The operating piston separates from the bulkhead
- High pressure air flows around the operating piston between it and the bulkhead
- The area of the shaft is much smaller
- The up force is much larger
- The shuttle flies up opening the ports discharging high pressure air from the firing chamber
- The mid chamber is flooded
- The water in the mid chamber is discharged→cavitation

3. Not going ballistic
- The pressure in the firing chamber drops down
- The pressure in the operating chamber goes up creating an air cushion at the top of the operating chamber

Why do Airguns auto-fire?



4. Drain the air *before* retrieval

- The air in the operating chamber **(5)** is drained
- The pressure in the operating chamber goes down
- The pressure in the operating chambers falls below the pressure in the firing chamber **(4)**
- The difference in area of the operating piston **(3)** is not sufficiently larger than the area of the firing piston **(2)** to hold the shutle
- The gun auto-fires
- Unsafe to drain onboard because it would auto-fire (unless the drainage is very very slow)
- Must drain the air in the water *before* retrieval
- Don’t drain the air completely because we don’t want to risk flooding the firing chamber
- Solution: drain it to low pressure but above ambient